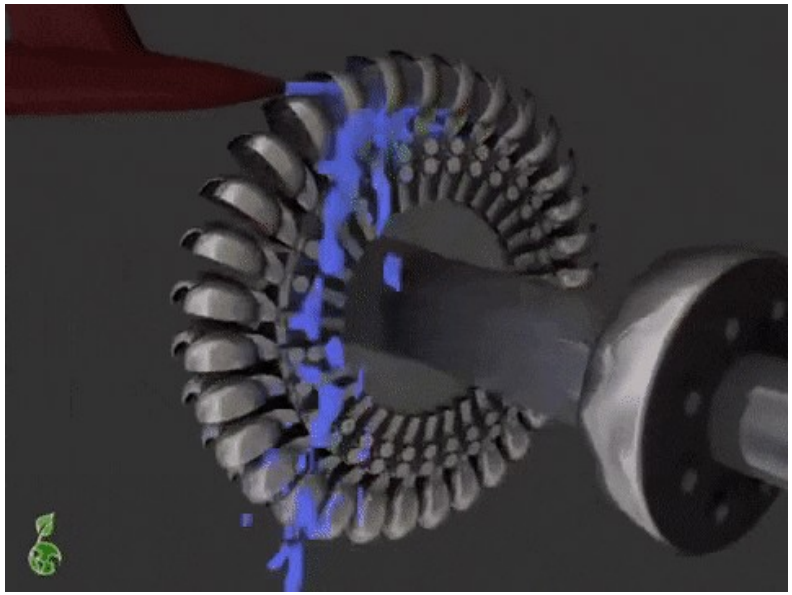
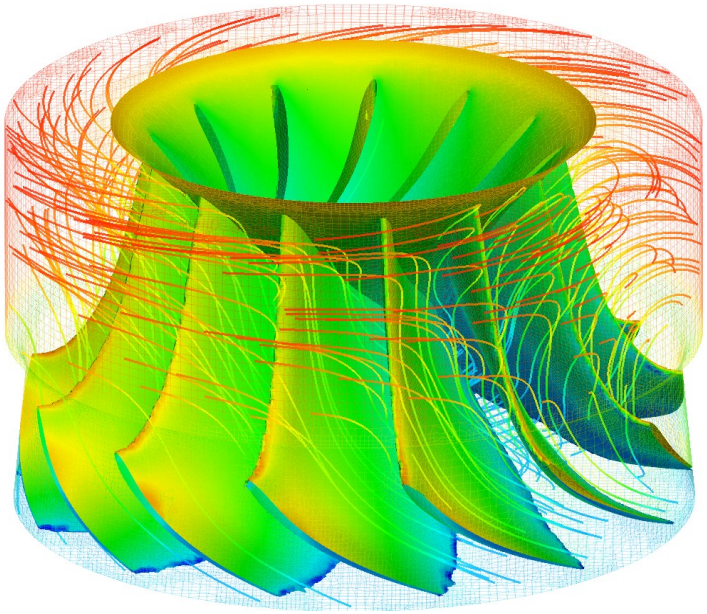
ntroduction of Hydraulics Machines





Hydraulics Machine

- Hydraulic machines are defined as those machines which convert either hydraulic energy (energy possessed by water) into mechanical energy or mechanical energy into hydraulic energy.

- The hydraulic machines, which convert the hydraulic energy into mechanical energy, are called *turbines*

- The hydraulic machines which convert the mechanical energy into hydraulic energy are called *pumps*

Thus,

- The study of hydraulic machines consists of study of turbines and pumps.

- Turbines consists of mainly study of **Pelton turbine, Francis Turbine and Kaplan Turbine**

- Pumps consist of study of **centrifugal pump** and **Reciprocating pumps.**

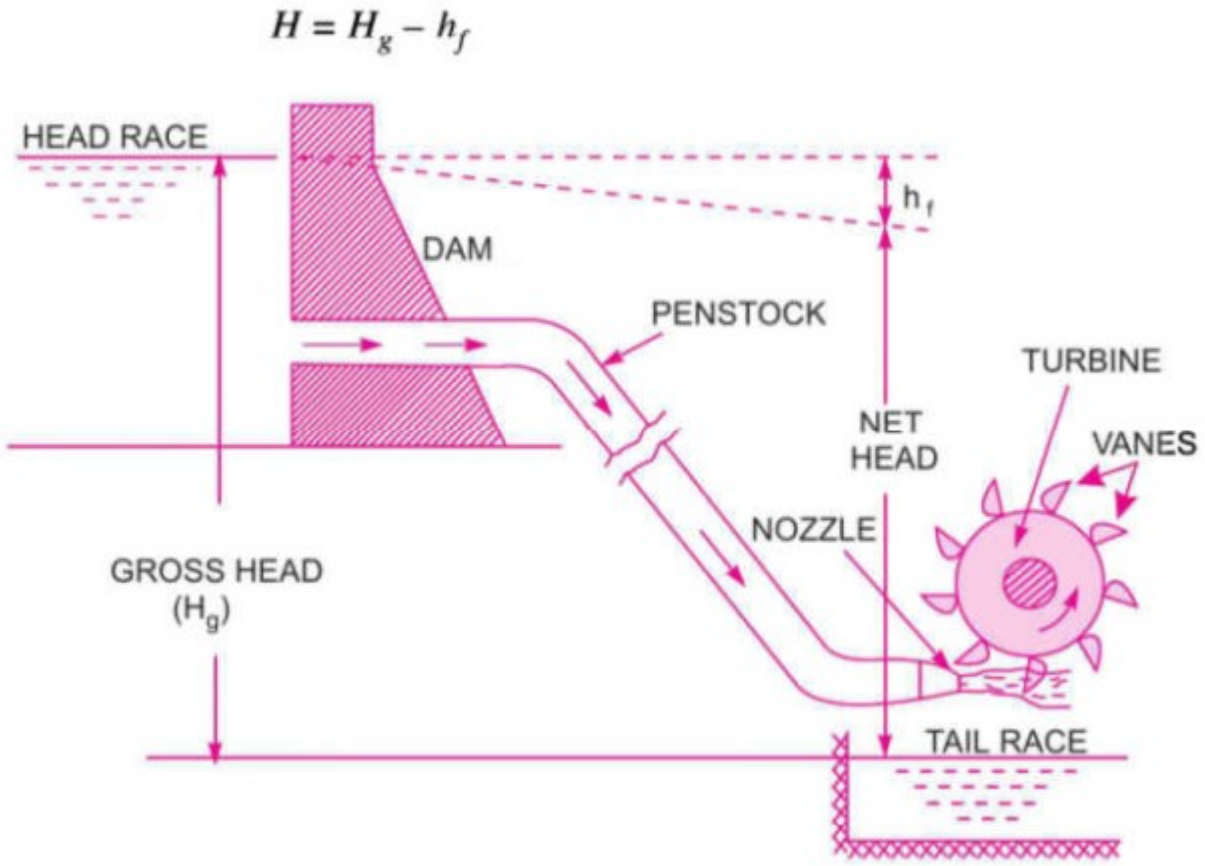
Turbines

- Turbines are defined as the hydraulic machines which convert hydraulic energy into mechanical energy.

- This mechanical energy is used in running an electric generator which is directly coupled to the shaft of the turbine. Thus the mechanical energy is converted into electrical energy.

- The electric power which is obtained from the hydraulic energy (energy of water) is known as *Hydroelectric power.*
- At present the generation of hydroelectric power is the cheapest as compared by the power generated by other sources such as oil, coal etc

Layout of a Hydroelectric Power Plant (Pelton Turbine)



Layout of a hydroelectric power plant.

Classification of Hydraulic Turbines

According to the type of energy at inlet :

Impulse turbine, and Reaction turbine.

According to the direction of flow through runner :

Tangential flow turbine Radial flow turbine

Axial flow Turbine Mixed flow turbine

According to head at the inlet of turbine

High head turbine Medium head turbine

Low head turbine

According to the specific speed of the turbine :

Low specific head turbine Medium specific speed turbine

High specific speed turbine

Impulse Turbine

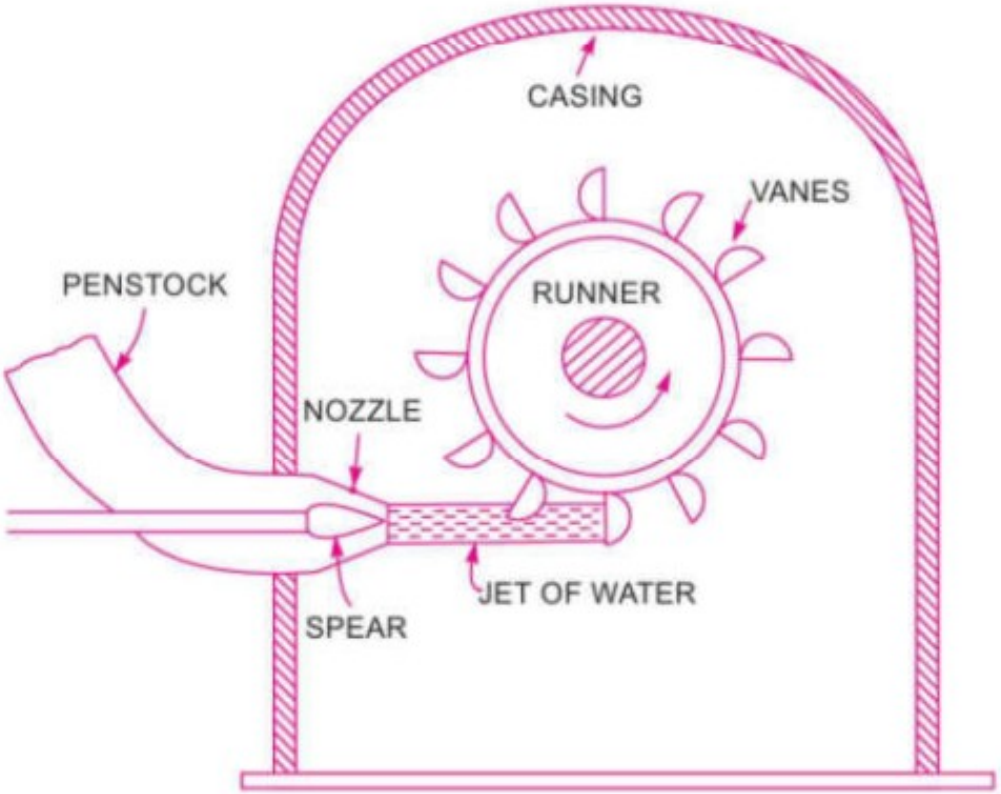
If at the inlet of the turbine, the energy available is only kinetic energy, the turbine is known as impulse turbine.

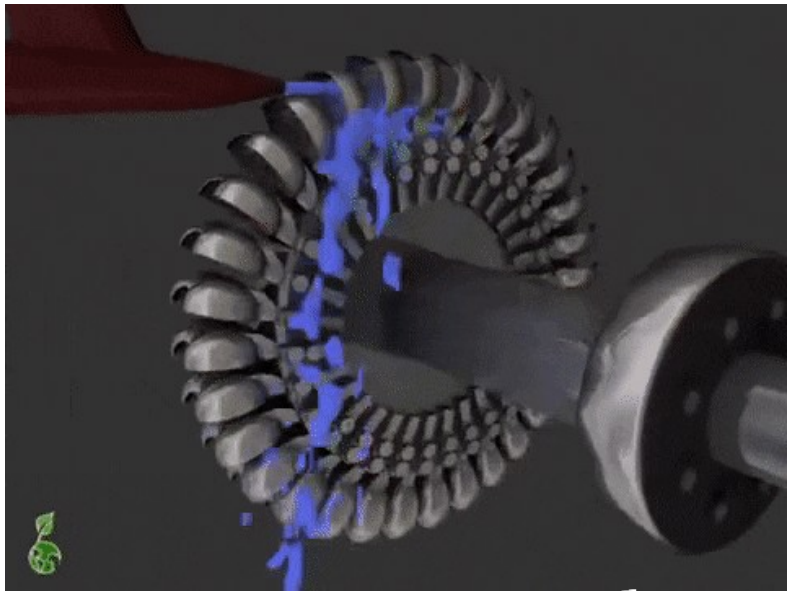
Reaction Turbine

If at the inlet of the turbine, the water possesses kinetic energy as well as pressure energy, the turbine is known as reaction turbine

Pelton Turbine

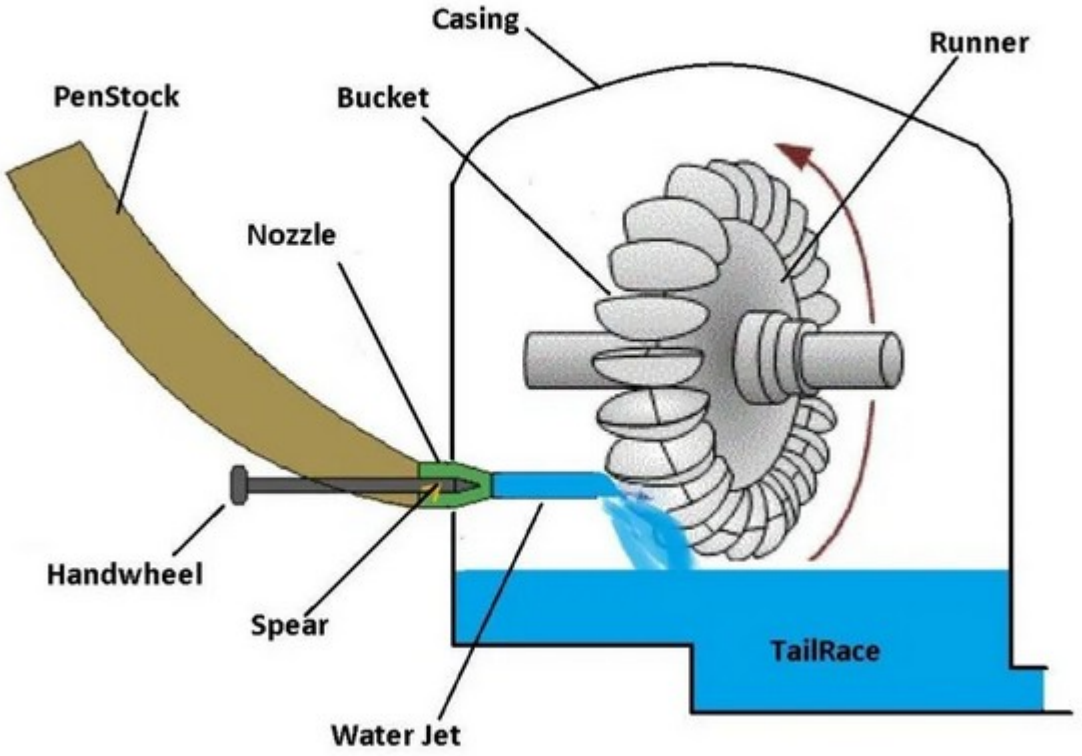
Tangential flow impulse





Pelton turbine

The Pelton-wheel is an impulsive turbine used for high heads of water. This turbine was discovered by the American engineer L.A. Pelton. The energy available at the inlet of the Pelton turbine is only kinetic energy. The pressure at the inlet and outlet of the turbine is atmospheric pressure. It has the following main components



Advantages:

1.Simple in construction and easy to maintain.

2.This turbine has high efficiency.

3.They work at atmospheric pressure so no problem of leakage.

4.It is easy to assemble.

Disadvantages:

5.This is not the best turbines for low-pressure streams by a high flow rate.

6.Impulse turbines are large in size compare to others.

7.Efficiency decreases with time.

8.It is costly to install.

Force Exerted by a Jet of Water on an unsymmetrical Moving Curved Plate when Jet Strikes Tangentially at one of the Tips

Figure shows a jet of water striking a moving curved plate (also called vane) tangentially, at one of its tips. As the jet strikes tangentially, the loss of energy due to impact of the jet will be zero. In this case as plate is moving, the velocity with which jet of water strikes is equal to the relative velocity of the jet with respect to the plate. Also as the plate is moving in different direction of the jet, the relative velocity at inlet will be equal to the vector difference of the velocity

Let V_1 = Velocity of the jet at inlet.

u_1 = Velocity of the plate (vane) at inlet.

V_{r_1} = Relative velocity of jet and plate at inlet.

α = Angle between the direction of the jet and direction of motion of the plate, also called guide blade angle.

θ = Angle made by the relative velocity (V_{r_2}) with the direction of motion at inlet also called vane angle at inlet.

V_{w_1} and V_{f_1} = The components of the velocity of the jet V_1, in the direction of motion and perpendicular to the direction of motion of the vane respectively.

V_{w_1} = It is also known as velocity of whirl at inlet.

V_{f_1} = It is also known as velocity of flow at inlet.

V_2 = Velocity of the jet, leaving the vane or velocity of jet at outlet of the vane.

u_2 = Velocity of the vane at outlet.

V_{r_2} = Relative velocity of the jet with respect to the vane at outlet.

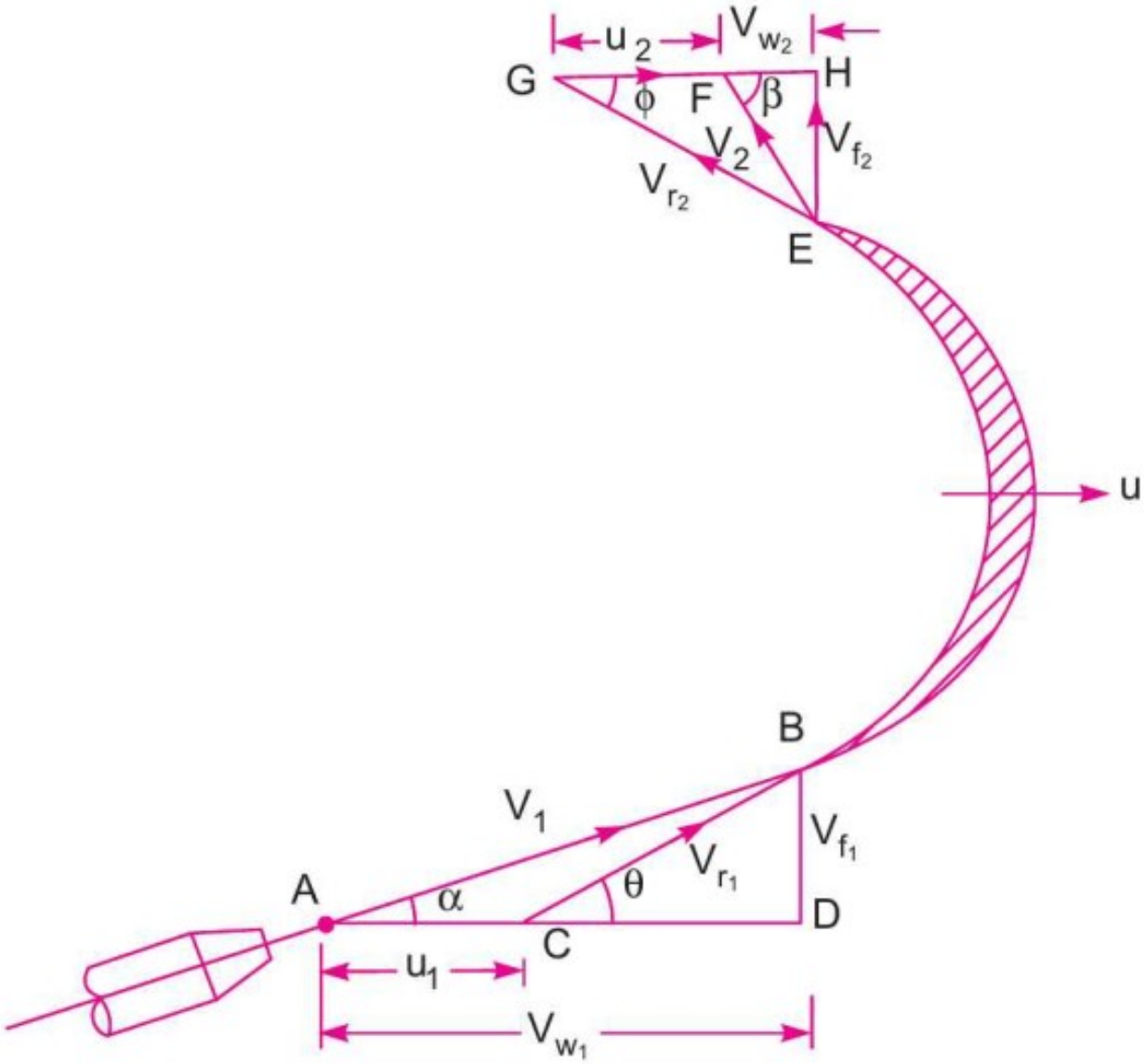
β = Angle made by the velocity V_2 with the direction of motion of the vane at outlet.

ϕ = Angle made by the relative velocity V_{r_2} with the direction of motion of the vane at outlet and also called vane angle at outlet.

V_{w_1} and V_{f_1} = Components of the velocity V_2, in the direction of motion of vane and perpendicular to the direction of motion of vane at outlet.

V_{w_2} = It is also called the velocity of whirl at outlet.

V_{f_2} = Velocity of flow at outlet.



Jet striking a moving curved vane at one of the tips

$\therefore$ Force exerted by the jet in the direction of motion

F_x = Mass of water striking per sec × [Initial velocity with which jet strikes in the direction of motion – Final velocity of jet in the direction of motion]

...(*ii*)

But initial velocity with which jet strikes the vane = V_{r_1}

The component of this velocity in the direction of motion

$$= V_{r_1} \cos \theta = (V_{w_1} - u_1)$$

Similarly, the component of the relative velocity at outlet in the direction of motion = $- V_{r_2} \cos \phi$

$$= - [u_2 + V_{w_2}]$$

–ve sign is taken as the component of V_{r_2} in the direction of motion is in the opposite direction.

Substituting the equation (*i*) and all above values of the velocities in equation (*ii*), we get

$$F_x = \rho a V_{r_1} [(V_{w_1} - u_1) - \{ - (u_2 + V_{w_2})\}] = \rho a V_{r_1} [V_{w_1} - u_1 + u_2 + V_{w_2}]$$

$$= \rho a V_{r_1} [V_{w_1} + V_{w_2}] \qquad (\because \quad u_1 = u_2) \quad ...(iii)$$

Equation (*iii*) is true only when angle β shown in Fig. 17.15 is an acute angle. If $\beta = 90°$, the $V_{w_2} = 0$, then equation (*iii*) becomes as,

$$F_x = \rho a V_{r_1} [V_{w_1}]$$

If β is an obtuse angle, the expression for F_x will become

$$F_x = \rho a V_{r_1} [V_{w_1} - V_{w_2}]$$

Thus in general, F_x is written as $F_x = \rho a V_{r_1} [V_{w_1} \pm V_{w_2}]$

Work done per second on the vane by the jet

= Force × Distance per second in the direction of force

$= F_x \times u = \rho a V_{r_1} [V_{w_1} \pm V_{w_2}] \times u$

$\therefore$ Work done per second per unit weight of fluid striking per second

$$= \frac{\rho a V_{r_1} \left[V_{w_1} \pm V_{w_2} \right] \times u}{\text{Weight of fluid striking/s}} \frac{\text{Nm/s}}{\text{N/s}} = \frac{\rho a V_{r_1} \left[V_{w_1} \pm V_{w_2} \right] \times u}{g \times \rho a V_{r_1}} = \text{Nm/N}$$

$$= \frac{1}{g} [V_{w_1} \pm V_{w_2}] \times u \text{ Nm/N}$$

Work done/sec per unit mass of fluid striking per second

Problem *A jet of water having a velocity of 20 m/s strikes a curved vane, which is moving with a velocity of 10 m/s. The jet makes an angle of 20° with the direction of motion of vane at inlet and leaves at an angle of 130° to the direction of motion of vane an outlet. Calculate :*

(i) Vane angles, so that the water enters and leaves the vane without shock.

(ii) Work done per second per unit weight of water striking (or work done per unit weight of water striking) the vane per second.

Solution. Given :

Velocity of jet, $V_1 = 20$ m/s

Velocity of vane, $u_1 = 10$ m/s

Angle made by jet at inlet, with direction of motion of vane,

$$\alpha = 20°$$

Angle made by the leaving jet, with the direction of motion

$$= 130°$$

$$\therefore \quad \beta = 180° - 130° = 50°$$

In this problem, $u_1 = u_2 = 10$ m/s

$$V_{r_1} = V_{r_2}$$

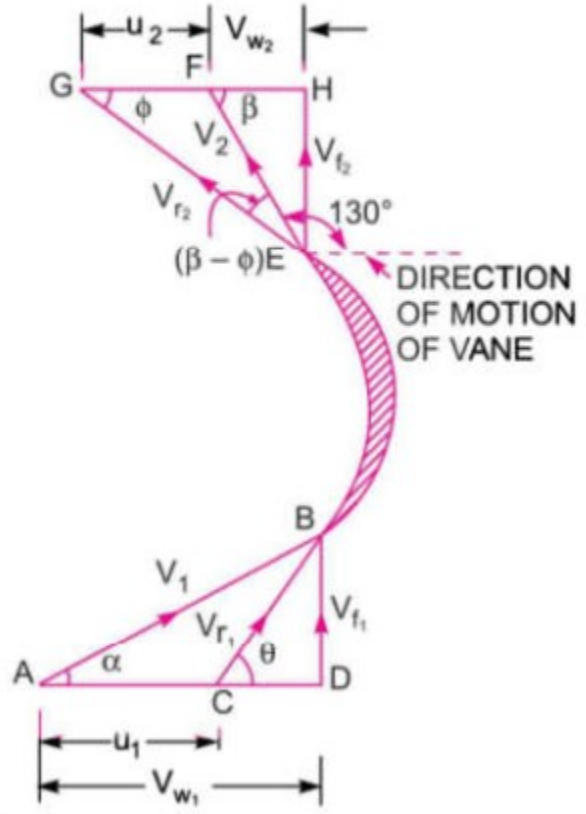


Fig.

(*i*) **Vane Angle** means angle made by the relative velocities at inlet and outlet, *i.e.*, θ and ϕ.

From Fig. in ΔABD, we have $\tan \theta = \dfrac{BD}{CD}$

$$= \frac{V_{f_1}}{AD - AC} = \frac{V_{f_1}}{V_{w_1} - u_1} \quad ...(i)$$

where $V_{f_1} = V_1 \sin \alpha = 20 \times \sin 20° = 6.84$ m/s

$V_{w_1} = V_1 \cos \alpha = 20 \times \cos 20^\circ = 18.794$ m/s.

$u_1 = 10$ m/s

$$\therefore \qquad \tan \theta = \frac{6.84}{18.794 - 10} = .7778 \text{ or } \theta = 37.875^\circ$$

$$\therefore \qquad \theta = \mathbf{37^\circ\ 52.5'.\ Ans.}$$

From, ΔABC, $\qquad \sin \theta = \dfrac{V_{f_1}}{V_{r_1}}$ or $V_{r_1} = \dfrac{V_{f_1}}{\sin \theta} = \dfrac{6.84}{\sin 37.875^\circ} = 11.14$

$$\therefore \qquad V_{r_2} = V_{r_1} = 11.14 \text{ m/s.}$$

From, ΔEFG, applying sine rule, we have

$$\frac{V_{r_2}}{\sin (180^\circ - \beta)} = \frac{u_2}{\sin (\beta - \phi)}$$

or $$\frac{11.14}{\sin \beta} = \frac{10}{\sin [\beta - \phi]} \quad \text{or} \quad \frac{11.14}{\sin 50^\circ} = \frac{10}{\sin [50^\circ - \phi]} \qquad (\because\ \beta = 50^\circ)$$

$$\therefore \qquad \sin (50^\circ - \phi) = \frac{10 \times \sin 50^\circ}{11.14} = 0.6876 = \sin 43.44^\circ$$

$$\therefore \qquad 50^\circ - \phi = 43.44^\circ \quad \text{or} \quad \phi = 50^\circ - 43.44^\circ = 6.56^\circ$$

$$\therefore \qquad \phi = \mathbf{6^\circ\ 33.6'.\ Ans.}$$

(*ii*) Work done per second per unit weight of the water striking the vane per second is given by equation (17.21) as

$$= \frac{1}{g} [V_{w_1} + V_{w_2}] \times u \text{ Nm/N (+ ve sign is taken as } \beta \text{ is an acute angle)}$$

where $V_{w_1} = 18.794$ m/s, $V_{w_2} = GH - GF = V_{r_2} \cos \phi - u_2 = 11.14 \times \cos 6.56^\circ - 10 = 1.067$ m/s

$u = u_1 = u_2 = 10$ m/s

$\therefore$ Work done per unit weight of water

$$= \frac{1}{9.81} [18.794 + 1.067] \times 10 \text{ Nm/N} = \mathbf{20.24 \text{ Nm/N. Ans.}}$$

Mathematical Analysis

Definitions Of Heads and Efficiencies of a Pelton Turbine

Gross Head: The difference between the head race level and tail race level when no water is flowing is known as Gross Head. It is denoted by H_g .

Net Head : $H = H_g - h_f$

where H_g = Gross head, $h_f = \dfrac{4 \times f \times L \times V^2}{D \times 2g}$,

in which

V = Velocity of flow in penstock,

L = Length of penstock,

D = Diameter of penstock.

Efficiencies of a Tu

Hydraulic Efficiency::

$$\eta_h = \frac{\text{Power delivered to runner}}{\text{Power supplied at inlet}} = \frac{\text{R.P.}}{\text{W.P.}}$$

where R.P. = Power delivered to runner *i.e.*, runner power

$$= \frac{W}{g}\frac{\left[V_{w_1} \pm V_{w_2}\right] \times u}{1000} \text{ kW} \qquad \text{...for Pelton Turbine}$$

$$= \frac{W}{g}\frac{\left[V_{w_1} u_1 \pm V_{w_2} u_2\right]}{1000} \text{ kW} \qquad \text{...for a radial flow turbine}$$

W.P. = Power supplied at inlet of turbine and also called water power

$$= \frac{W \times H}{1000} \text{ kW}$$

where W = Weight of water striking the vanes of the turbine per second

$= \rho g \times Q$ in which Q = Volume of water/s,

V_{w_1} = Velocity of whirl at inlet,

V_{w_2} = Velocity of whirl at outlet,

u = Tangential velocity of vane,

u_1 = Tangential velocity of vane at inlet for radial vane,

u_2 = Tangential velocity of vane at outlet for radial vane,

H = Net head on the turbine.

Mechanical Efficie

$$\eta_m = \frac{\text{Power at the shaft of the turbine}}{\text{Power delivered by water to the runner}} = \frac{\text{S.P.}}{\text{R.P.}}$$

Volumetric Efficiency:

$$\eta_v = \frac{\text{Volume of water actually striking the runner}}{\text{Volume of water supplied to the turbine}}$$

Overall Efficienc

$$\eta_o = \frac{\text{Volume available at the shaft of the turbine}}{\text{Power supplied at the inlet of the turbine}} = \frac{\text{Shaft power}}{\text{Water power}}$$

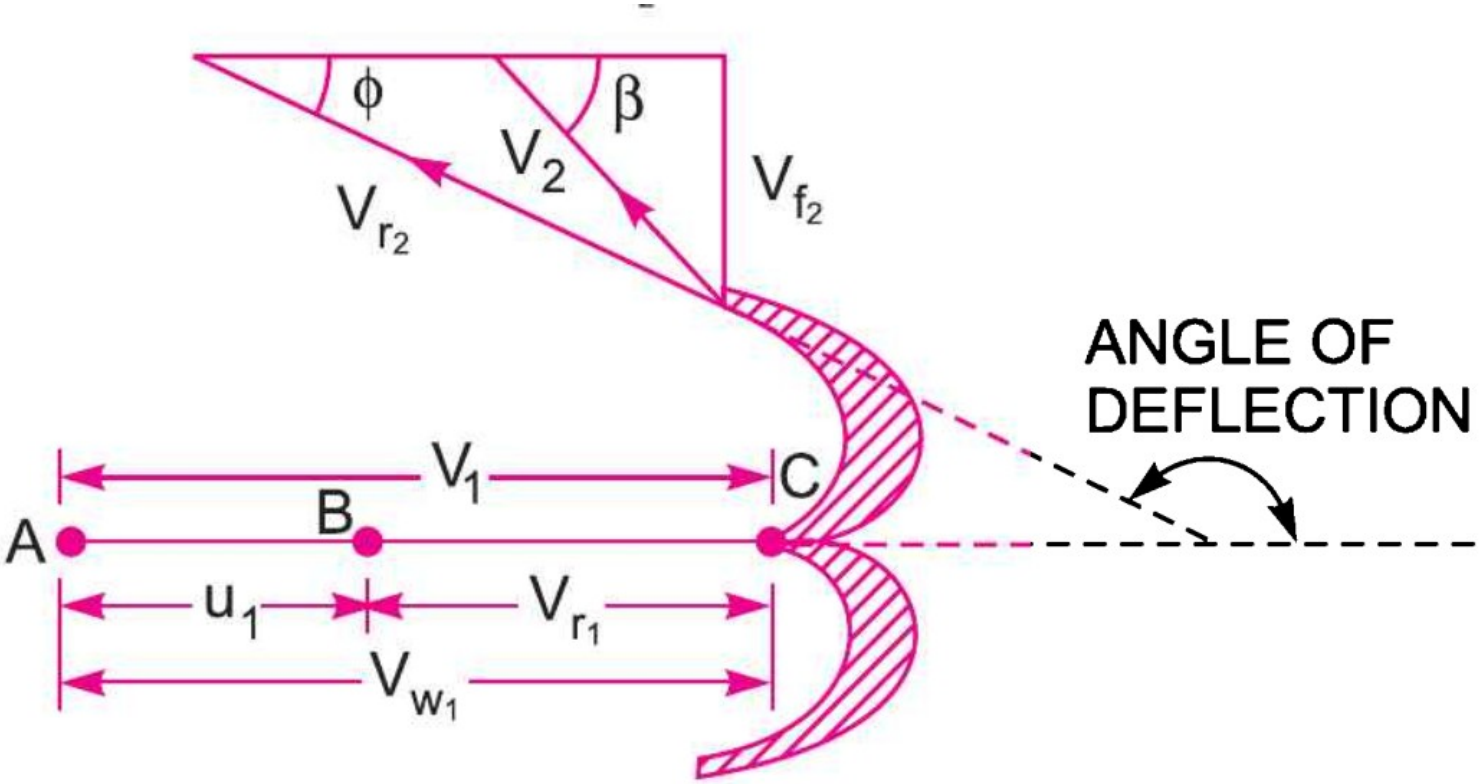
$$= \frac{\text{S.P.}}{\text{W.P.}}$$

$$= \frac{\text{S.P.}}{\text{W.P.}} \times \frac{\text{R.P.}}{\text{R.P.}}$$

$$= \frac{\text{S.P.}}{\text{R.P.}} \times \frac{\text{R.P.}}{\text{W.P.}}$$

$$= \eta_m \times \eta_h$$

Velocity Triangles and Work Done for Pelton Wheel



Let H = Net head acting on the Pelton wheel

$= H_g - h_f$

where H_g = Gross head and $h_f = \dfrac{4fLV^2}{D^* \times 2g}$

where D^* = Dia. of Penstock, N = Speed of the wheel in r.p.m.,

D = Diameter of the wheel, d = Diameter of the jet.

Then V_1 = Velocity of jet at inlet = $\sqrt{2gH}$

$$u = u_1 = u_2 = \frac{\pi DN}{60}.$$

The velocity triangle at inlet will be a straight line where

$$V_{r_1} = V_1 - u_1 = V_1 - u$$

$$V_{w_1} = V_1$$

$$\alpha = 0^\circ \text{ and } \theta = 0^\circ$$

From the velocity triangle at outlet, we have

$$V_{r_2} = V_{r_1} \text{ and } V_{w_2} = V_{r_2} \cos \phi - u_2.$$

The force exerted by the jet of water in the direction of motion is given by equation

$$F_x = \rho a V_1 [V_{w_1} + V_{w_2}]$$

As the angle β is an acute angle, +ve sign should be taken. Also this is the case of series of vanes, the mass of water striking is $\rho a V_1$ and not $\rho a V_{r_1}$. In equation (18.8), 'a' is the area of the jet which is given as

$$a = \text{Area of jet} = \frac{\pi}{4} d^2.$$

Now work done by the jet on the runner per second

$$= F_x \times u = \rho a V_1 [V_{w_1} + V_{w_2}] \times u \text{ Nm/s}$$

Power given to the runner by the jet

$$= \frac{\rho a V_1 \left[V_{w_1} + V_{w_2}\right] \times u}{1000} \text{ kW}$$

Work done/s per unit weight of water striking/s

$$= \frac{\rho a V_1 \left[V_{w_1} + V_{w_2}\right] \times u}{\text{Weight of water striking/s}}$$

$$= \frac{\rho a V_1 \left[V_{w_1} + V_{w_2}\right] \times u}{\rho a V_1 \times g} = \frac{1}{g} \left[V_{w_1} + V_{w_2}\right] \times u$$

The energy supplied to the jet at inlet is in the form of kinetic energy and is equal to $\frac{1}{2} m V^2$

$\therefore$ K.E. of jet per second $= \frac{1}{2} (\rho a V_1) \times V_1^2$

$\therefore$ K.E. of jet per second $= \frac{1}{2}(\rho a V_1) \times V_1^2$

$\therefore$ **Hydraulic efficiency,** $\eta_h = \frac{\text{Work done per second}}{\text{K.E. of jet per second}}$

$$= \frac{\rho a V_1 \left[V_{w_1} + V_{w_2}\right] \times u}{\frac{1}{2}(\rho a V_1) \times V_1^2} = \frac{2\left[V_{w_1} + V_{w_2}\right] \times u}{V_1^2}$$

Now $V_{w_1} = V_1,\ V_{r_1} = V_1 - u_1 = (V_1 - u)$

$\therefore$ $V_{r_2} = (V_1 - u)$

and $V_{w_2} = V_{r_2} \cos\phi - u_2 = V_{r_2} \cos\phi - u = (V_1 - u)\cos\phi - u$

Substituting the values of V_{w_1} and V_{w_2} in equation (18.12),

$$\eta_h = \frac{2\left[V_1 + (V_1 - u)\cos\phi - u\right] \times u}{V_1^2}$$

$$= \frac{2\left[V_1 - u + (V_1 - u)\cos\phi\right] \times u}{V_1^2} = \frac{2(V_1 - u)\,[1 + \cos\phi]\,u}{V_1^2}.$$

The efficiency will be maximum for a given value of V_1 when

$$\frac{d}{du}(\eta_h) = 0 \quad \text{or} \quad \frac{d}{du}\left[\frac{2u(V_1 - u)(1 + \cos\phi)}{V_1^2}\right] = 0$$

or $$\frac{(1 + \cos\phi)}{V_1^2}\frac{d}{du}(2uV_1 - 2u^2) = 0 \quad \text{or} \quad \frac{d}{du}[2uV_1 - 2u^2] = 0 \quad \left(\because \frac{1 + \cos\phi}{V_1^2} \neq 0\right)$$

or $$2V_1 - 4u = 0 \quad \text{or} \quad u = \frac{V_1}{2}$$

Equation (18.14) states that hydraulic efficiency of a Pelton wheel will be maximum when the velocity of the wheel is half the velocity of the jet of water at inlet. The expression for maximum efficiency will be obtained by substituting the value of $u = \frac{V_1}{2}$ in equation (18.13).

$$\therefore \quad \text{Max. } \eta_h = \frac{2\left(V_1 - \frac{V_1}{2}\right)(1 + \cos\phi) \times \frac{V_1}{2}}{V_1^2}$$

$$= \frac{2 \times \frac{V_1}{2}(1 + \cos\phi)\frac{V_1}{2}}{V_1^2} = \frac{(1 + \cos\phi)}{2}.$$

Points to be Remembered for Pelton Wheel

(*i*) The velocity of the jet at inlet is given by $V_1 = C_v\sqrt{2gH}$

where C_v = Co-efficient of velocity = 0.98 or 0.99

H = Net head on turbine

(*ii*) The velocity of wheel (u) is given by $u = \phi\sqrt{2gH}$

where ϕ = Speed ratio. The value of speed ratio varies from 0.43 to 0.48.

(*iii*) The angle of deflection of the jet through buckets is taken at 165° if no angle of deflection is given.

(*iv*) The mean diameter or the pitch diameter D of the Pelton wheel is given by

$$u = \frac{\pi DN}{60} \text{ or } D = \frac{60u}{\pi N}.$$

(*v*) **Jet Ratio.** It is defined as the ratio of the pitch diameter (D) of the Pelton wheel to the diameter of the jet (d). It is denoted by 'm' and is given as

$$m = \frac{D}{d} \text{ (= 12 for most cases)}$$

(*vi*) Number of buckets on a runner is given by

$$Z = 15 + \frac{D}{2d} = 15 + 0.5 \text{ m}$$

where m = Jet ratio

(*vii*) **Number of Jets.** It is obtained by dividing the total rate of flow through the turbine by the rate of flow of water through a single jet.

Selection of Turbine

S. No.	Specific speed		Types of turbine
	(M.K.S.)	(S.I.)	
1.	10 to 35	8.5 to 30	Pelton wheel with single jet
2.	35 to 60	30 to 51	Pelton wheel with two or more jets
3.	60 to 300	51 to 225	Francis turbine
4.	300 to 1000	255 to 860	Kaplan or Propeller turbine

S. No.	Head in metres	Specific speed	Type of turbine
1.	300 m or more	8.5 to 50	Pelton wheel with single or multiple jet
2.	150 to 300 m	30 to 85	Pelton or Francis turbine
3.	50 to 150 m	86 to 200	Francis turbine
4.	Less than 50 m	256 to 860	Kaplan or propeller

Solved Examples

Problem 18.1 *A Pelton wheel has a mean bucket speed of 10 metres per second with a jet of water flowing at the rate of 700 litres/s under a head of 30 metres. The buckets deflect the jet through an angle of 160°. Calculate the power given by water to the runner and the hydraulic efficiency of the turbine. Assume co-efficient of velocity as 0.98.*

Solution. Given :

Speed of bucket, $u = u_1 = u_2 = 10$ m/s

Discharge, $Q = 700$ litres/s $= 0.7$ m^3/s, Head of water, $H = 30$ m

Angle of deflection $= 160°$

$\therefore$ Angle, $\phi = 180° - 160° = 20°$

Co-efficient of velocity, $C_v = 0.98$.

The velocity of jet, $V_1 = C_v\sqrt{2gH} = 0.98\ \sqrt{2 \times 9.81 \times 30} = 23.77$ m/s

$\therefore$ $V_{r_1} = V_1 - u_1 = 23.77 - 10$

$= 13.77$ m/s

$V_{w_1} = V_1 = 23.77$ m/s

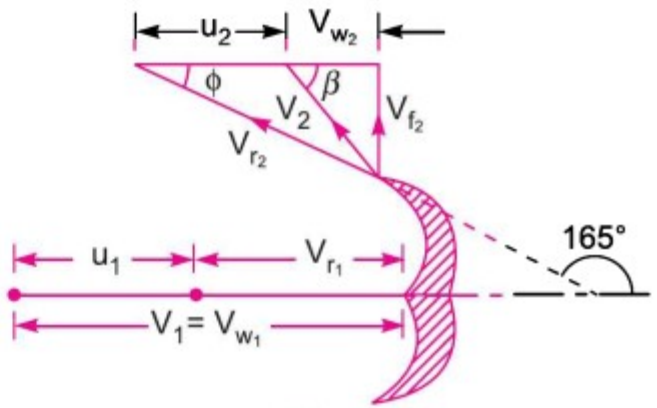


Fig. 18.6

From outlet velocity triangle,

$V_{r_2} = V_{r_1} = 13.77$ m/s

$V_{w_2} = V_{r_2} \cos \phi - u_2$

$= 13.77 \cos 20° - 10.0 = 2.94$ m/s

Work done by the jet per second on the runner is given by equation (18.9) as

$= \rho a V_1 \left[V_{w_1} + V_{w_2}\right] \times u$

$= 1000 \times 0.7 \times [23.77 + 2.94] \times 10$ ($\because$ $aV_1 = Q = 0.7$ m^3/s)

$= 186970$ Nm/s

$\therefore$ Power given to turbine $= \dfrac{186970}{1000} =$ **186.97 kW. Ans.**

The hydraulic efficiency of the turbine is given by equation (18.12) as

$$\eta_h = \frac{2\left[V_{w_1} + V_{w_2}\right] \times u}{V_1^2} = \frac{2[23.77 + 2.94] \times 10}{23.77 \times 23.77}$$

$=$ **0.9454** or **94.54%. Ans.**

Problem 18.3 *The penstock supplies water from a reservoir to the Pelton wheel with a gross head of 500 m. One third of the gross head is lost in friction in the penstock. The rate of flow of water through the nozzle fitted at the end of the penstock is 2.0 m^3/s. The angle of deflection of the jet is 165°. Determine the power given by the water to the runner and also hydraulic efficiency of the Pelton wheel. Take speed ratio = 0.45 and C_v = 1.0.*

Solution. Given :

Gross head, $H_g = 500$ m

Head lost in friction, $h_f = \frac{H_g}{3} = \frac{500}{3} = 166.7$ m

$\therefore$ Net head, $H = H_g - h_f = 500 - 166.7 = 333.30$ m

Discharge, $Q = 2.0$ m^3/s

Angle of deflection $= 165°$

$\therefore$ Angle, $\phi = 180° - 165° = 15°$

Speed ratio $= 0.45$

Co-efficient of velocity, $C_v = 1.0$

Velocity of jet, $V_1 = C_v\sqrt{2gH} = 1.0 \times \sqrt{2 \times 9.81 \times 333.3} = 80.86$ m/s

Velocity of wheel, $u = \text{Speed ratio} \times \sqrt{2gH}$

or $u = u_1 = u_2 = 0.45 \times \sqrt{2 \times 9.81 \times 333.3} = 36.387$ m/s

$\therefore$ $V_{r_1} = V_1 - u_1 = 80.86 - 36.387$

$= 44.473$ m/s

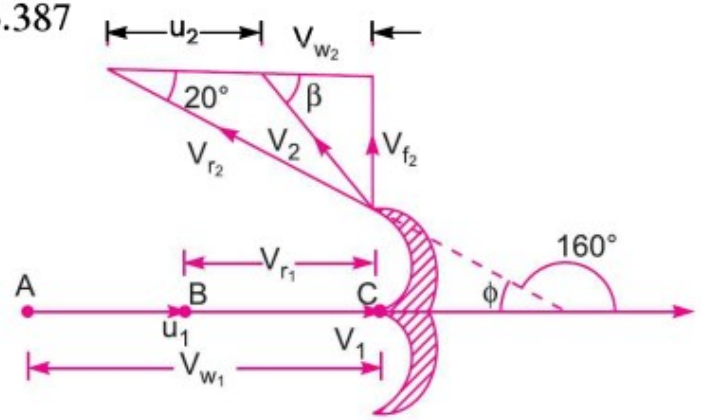
Also $V_{w_1} = V_1 = 80.86$ m/s

From outlet velocity triangle, we have

$V_{r_2} = V_{r_1} = 44.473$

$V_{r_2} \cos \phi = u_2 + V_{w_2}$

$44.473 \quad 15° \quad 36.387 \quad V$



$$V_{r_2} \cos \phi = u_2 + V_{w_2}$$

or $$44.473 \cos 15° = 36.387 + V_{w_2}$$

or $$V_{w_2} = 44.473 \cos 15° - 36.387 = 6.57 \text{ m/s.}$$

Work done by the jet on the runner per second is given by equation (18.9) as

$$\rho a V_1 [V_{w_1} + V_{w_2}] \times u = \rho Q [V_{w_1} + V_{w_2}] \times u \qquad (\because \quad aV_1 = Q)$$

$$= 1000 \times 2.0 \times [80.86 + 6.57] \times 36.387 = 6362630 \text{ Nm/s}$$

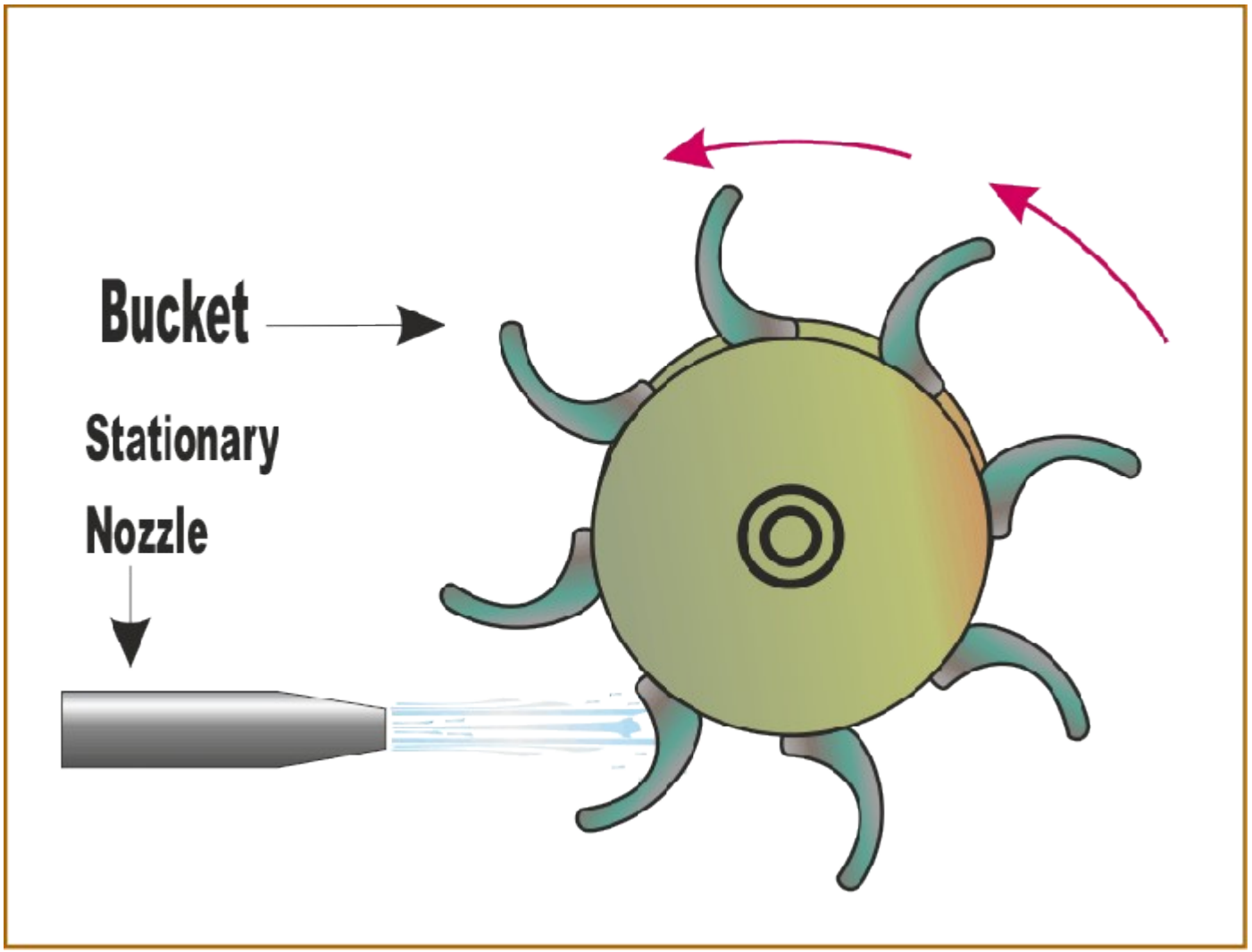
$\therefore$ Power given by the water to the runner in kW

$$= \frac{\text{Work done per second}}{1000} = \frac{6362630}{1000} = \mathbf{6362.63 \text{ kW. Ans.}}$$

Hydraulic efficiency of the turbine is given by equation (18.12) as

$$\eta_h = \frac{2\left[V_{w_1} + V_{w_2}\right] \times u}{V_1^2} = \frac{2[80.86 + 6.57] \times 36.387}{80.86 \times 80.86}$$

$$= \mathbf{0.9731} \text{ or } \mathbf{97.31\%. Ans.}$$


Bucket
Stationary
Nozzle